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RESEARCH DEPARTMENT

FLUCTUATION NOISE IN TWO FORMS OF THE NTSC COLOUR TELEVISION SYSTEM

Report No. T-099

(1962/44)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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D. Maurice

A.V. Lord, B.Sc.Tech., A.M.I.E.E.

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SUMMARY

A recently proposed modification to the coding of NTSC-type colour television claims to offer some improvements in the picture displayed by both colour and black-and-white receivers. The effects of fluctuation noise in colour receivers are investigated for both the modified system and the normal form of NTSC system. The analysis assumes that "flat-spectrum" noise is added to the signal at a point prior to decoding in the receiver, and the visibility of this noise is calculated for a series of test colours; the results given include allowance for the reduction of receiver contrast ratio by ambient light falling upon the screen. It is shown that both systems have a substantially similar sensitivity to fluctuation noise. These findings are discussed in the light of experiments carried out in the U.S.A. and Britain.

1. INTRODUCTION

A modification to the coding of NTSC-type colour television signals has been proposed recently.[1] It is claimed that this modification offers some improvements in the pictures displayed by both colour and monochrome receivers. In this report, the effects of fluctuation noise in colour receivers are investigated for both the modified and the normal forms of the NTSC system.

In general, the composite colour signal presented to the decoding circuits of a colour receiver will be accompanied by fluctuation noise; this noise is added to the signal in the radio-frequency stages of the receiver, including the aerial. The spectrum of the added noise is determined by the shape of the receiver pass-band and, in the case of vestigial-sideband reception, is non-uniform. Further, such a receiver introduces colour-signal distortion which results in crosstalk between the luminance and chrominance signals.[2,3]

For the purposes of comparison it has been assumed here that double-sideband reception is used; this form of reception introduces no inherent distortion and the noise added to the signal has a uniform spectrum.

2. GENERAL

Fig. 1 shows the spectrum of a typical "equiband"* colour signal and Fig. 2 illustrates the form of a decoder used to convert the composite signal at the receiver detector into signals suitable for a three-gun display.

* It is assumed that "colour-difference-signal" decoding is employed, and that asymmetric-sideband chrominance components are eliminated by a filter located before the decoder.

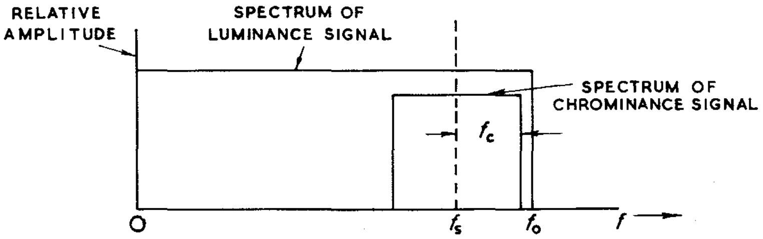

Fig. 1 - Composite signal spectrum

The composite signal has the form

$$E_M = E_L + \frac{1}{K_1}\left(E_R^{1/\gamma} - E_L\right)\cos\omega_s t + \frac{1}{K_2}\left(E_B^{1/\gamma} - E_L\right)\sin\omega_s t \tag{1}$$

where E_L represents a general form of luminance signal, and K_1 and K_2 determine the relative amplitudes of the chrominance components in the composite signal. If "flat" noise, of bandwidth f_O, is added to the signal before the decoder, wideband noise N_Y (r.m.s. value $\left(\overline{N_Y^2}\right)^{\frac{1}{2}}$) will accompany the signal E_L and the outputs of the two synchronous demodulators will be accompanied by noise of bandwidth f_c. The two low-bandwidth noise fluctuations will have equal r.m.s. values, but will have a quadrature relationship.

Let these two components be represented by N_c' and N_c''. If the synchronous demodulators are regarded as devices producing two outputs equal to the input signal multiplied by 2 $\cos\omega_s t$ and 2 $\sin\omega_s t$ respectively, it can be shown (see Appendix) that r.m.s. values of N_c' and N_c'', $\left(\overline{N_c'^2}\right)^{\frac{1}{2}}$ and $\left(\overline{N_c''^2}\right)^{\frac{1}{2}}$ are given by

$$\left(\overline{N_c'^2}\right)^{\frac{1}{2}} = \left(\overline{N_c''^2}\right)^{\frac{1}{2}} = \left(\overline{N_Y^2}\right)^{\frac{1}{2}} \cdot (2f_c/f_o)^{\frac{1}{2}} \tag{2}$$

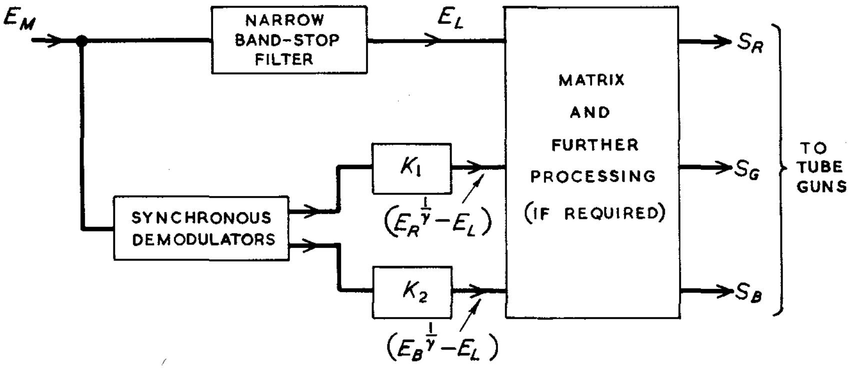
E_M
NARROW BAND-STOP FILTER
E_L
MATRIX AND FURTHER PROCESSING (IF REQUIRED)
S_R
S_G
S_B
TO TUBE GUNS
K_1
K_2
SYNCHRONOUS DEMODULATORS
$(E_R^{\frac{1}{\gamma}} - E_L)$
$(E_B^{\frac{1}{\gamma}} - E_L)$

Fig. 2 - General form of decoder

Such low-bandwidth noise fluctuations cause two forms of disturbance to the reproduced picture. First, they upset the relative proportions of the colour-difference signals $\left(E_R{}^{1/\gamma} - E_L\right)$ and $\left(E_B{}^{1/\gamma} - E_L\right)$, thus affecting the hue and saturation of the reproduction. Secondly, the properties of the decoder together with the non-linear brightness-against-drive-voltage characteristics of the display tube may prevent full exploitation of the "Constant Luminance Principle".[4] In such circumstances the colour-difference signals contribute to the luminance of the reproduction; the accompanying noise thus causes fluctuations of reproduced luminance.

This report is concerned solely with the total *luminance* contributions of the noise portrayed by the display, fluctuations of hue and saturation being relatively less visible by some 6 to 8 dB.[4]

The noise contributing to luminance may be considered as two separate parts. First, the luminance channel contains noise between zero frequency and f_c to which further contributions may be made by noise (of the same bandwidth) from the chrominance channels. Secondly, the luminance channel alone contributes noise between f_c and f_o. The amplitudes of these various contributions are determined by the decoding and display processes and are denoted, in the ensuing discussion, by the coefficients a (luminance channel), b $\left(E_R{}^{1/\gamma} - E_L \text{ chrominance channel}\right)$ and c $\left(E_B{}^{1/\gamma} - E_L \text{ chrominance channel}\right)$.

Recalling that the noise power at the decoder input is N_Y^2 and the synchronous detectors provide noise-power components $N_c'^2$ and $N_c''^2$ we note that the total low-frequency noise power (0 to f_c) is

$$N_{LF}^2 = \left(N_Y^2\, f_c/f_o\right)\left(a^2 + 2b^2 + 2c^2\right)$$

and the r.m.s. value

$$\left(\overline{N_{LF}^2}\right)^{\frac{1}{2}} = \left(\overline{N_Y^2}\right)^{\frac{1}{2}} \left\{f_c\ (a^2 + 2b^2 + 2c^2)/f_o\right\}^{\frac{1}{2}} \tag{3}$$

The high-frequency noise power, contributed by the luminance channel only, may be expressed by

$$N_{HF}^2 = N_Y^2 \cdot a^2 \cdot (f_o - f_c)/f_o$$

and the r.m.s. value is

$$\left(\overline{N_{HF}^2}\right)^{\frac{1}{2}} = \left(\overline{N_Y^2}\right)^{\frac{1}{2}} \cdot a \cdot \left\{(f_o - f_c)/f_o\right\}^{\frac{1}{2}} \tag{4}$$

Having given expressions for the luminance contributions for low- and high-frequency noise, it remains to deduce relationships defining the visibility of noise in relatively large picture areas; in areas containing considerable detail, effects such as beating between signal and noise may introduce added complications.

If the average brightness of the area is Y, the "r.m.s. visibility"* of l.f. noise will be, from (3)

$$\frac{\Delta Y_{LF}}{Y} = \left(\frac{\overline{N_Y^2}}{Y}\right)^{\frac{1}{2}} . \left\{f_c(a^2 + 2b^2 + 2c^2)/f_o\right\}^{\frac{1}{2}} \tag{5}$$

and for h.f. noise, from (4)

$$\frac{\Delta Y_{HF}}{Y} = \left(\frac{\overline{N_Y^2}}{Y}\right)^{\frac{1}{2}} . \; a\left\{(f_o - f_c)/f_c\right\}^{\frac{1}{2}} \tag{6}$$

3. LINEAR DECODING

Colour receivers employ display tubes whose "light output"-against-drive-voltage characteristics may be represented by a power law of exponent approximating to 2·2. In the interests of receiver economics and reliability the colour decoders used are of a form employing "linear" processes of detection, addition and subtraction.

Referring to Fig. 2 it will be seen that $E_R^{1/\gamma}$ and $E_B^{1/\gamma}$ may be recovered by adding E_L to $\left(E_R^{1/\gamma} - E_L\right)$ and $\left(E_B^{1/\gamma} - E_L\right)$. In the linear decoder the green colour-difference signal is recovered by the "matrixing" (taking a suitably weighted sum) of $\left(E_R^{1/\gamma} - E_L\right)$ and $\left(E_B^{1/\gamma} - E_L\right)$

From equation (1) and Fig. 2, therefore, we find that, in the presence of noise, the instantaneous signals applied to the display-tube guns are

$$S_R = E_R^{1/\gamma} + N_Y + K_1 N_c' \tag{7}$$

$$S_B = E_B^{1/\gamma} + N_Y + K_2 N_c'' \tag{8}$$

where S_R and S_B are signals applied to the tube guns.

The "matrixing" operation is defined by

$$E_{G\,diff} = -0{\cdot}51\left(E_R^{1/\gamma} - E_L\right) - 0{\cdot}19\left(E_B^{1/\gamma} - E_L\right) \tag{9}$$

where $E_{G\,diff}$ represents the green colour-difference signal.

As for equations (7) and (8), adding $E_L + N_Y$ and remembering that in equation (9) the colour-difference signals are now accompanied by N_c' and N_c'', we have

$$\begin{aligned} S_G &= E_L + N_Y - 0{\cdot}51\left\{\left(E_R^{1/\gamma} - E_L\right) + K_1 N_c'\right\} - 0{\cdot}19\left\{\left(E_B^{1/\gamma} - E_L\right) + K_2 N_c''\right\} \\ &= 1{\cdot}7\,E_L - 0{\cdot}51\,E_R^{1/\gamma} - 0{\cdot}19\,E_B^{1/\gamma} + N_Y - 0{\cdot}51 \,.\, K_1 \,.\, N_c' - 0{\cdot}19 \,.\, K_2 \,.\, N_c'' \end{aligned} \tag{10}$$

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*This term is based upon the Fechner fraction and, as used here, is defined as the ratio of the r.m.s. brightness fluctuation to the mean brightness.

Now each gun characteristic may be represented by

$$L = S^{\gamma}$$

where L is the "light output" from a phosphor as the result of an input signal S.

For small perturbations

$$\frac{\delta L}{\delta S} = \gamma S^{\gamma - 1} \tag{11}$$

and $S^{\gamma-1}$ tends to zero with S when $\gamma > 1$.

Thus the instantaneous "light outputs" from the three phosphors are, from (7), (8) and (10)

$$L_R = E_R + \gamma \, . \, E_R^{(\gamma-1)/\gamma} \, . \, (N_Y + K_1 \, N'_c) \tag{12}$$

$$L_B = E_B + \gamma \, . \, E_B^{(\gamma-1)/\gamma} \, . \, (N_Y + K_2 \, N''_c) \tag{13}$$

$$\begin{aligned} L_G = & \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma} \\ & + \gamma \, . \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma-1} . \, (N_Y - 0{\cdot}51 \, K_1 \, N'_c - 0{\cdot}19 \, K_2 \, N''_c) \end{aligned} \tag{14}$$

The total luminance is, therefore,

$$\begin{aligned} Y_T = & \; 0{\cdot}3L_R + 0{\cdot}11L_B + 0{\cdot}59L_G \\ = & \; 0{\cdot}3E_R + 0{\cdot}11E_B + 0{\cdot}59 \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma} \\ & + \gamma \, . \, N_Y \left\{0{\cdot}3 \, E_R^{(\gamma-1)/\gamma} + 0{\cdot}11 \, E_B^{(\gamma-1)/\gamma} + 0{\cdot}59 \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma-1}\right\} \\ & + \gamma \, . \, N'_c \left\{0{\cdot}3.K_1 \, E_R^{(\gamma-1)/\gamma} - 0{\cdot}59 \; 0{\cdot}51 \, K_1 \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma-1}\right\} \\ & + \gamma \, . \, N''_c \left\{0{\cdot}11 \, K_2 \, E_B^{(\gamma-1)/\gamma} - 0{\cdot}59 \; 0{\cdot}19 \, K_2 \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma-1}\right\} \end{aligned} \tag{15}$$

whence Y, a, b and c of equations (5) and (6) are

$$Y = 0{\cdot}3E_R + 0{\cdot}11E_B + 0{\cdot}59 \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma} \tag{16}$$

$$a = \gamma \left\{0{\cdot}3 \, E_R^{(\gamma-1)/\gamma} + 0{\cdot}11 \, E_B^{(\gamma-1)/\gamma} + 0{\cdot}59 \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma-1}\right\} \tag{17}$$

$$b = \gamma . 0{\cdot}3 \, . \, K_1 \left\{ E_R^{(\gamma-1)/\gamma} - \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma} \right)^{\gamma-1} \right\} \qquad (18)$$

$$c = \gamma . 0{\cdot}11 . \, K_2 \left\{ E_B^{(\gamma-1)/\gamma} - \left(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma} \right)^{\gamma-1} \right\} \qquad (19)$$

3.1 Specific Systems with Linear Decoding

The quantities Y, a, b and c may now be deduced for specific systems. For the NTSC system with NTSC decoding, we have

$$E_M = E_Y + \frac{1}{1{\cdot}14}\left(E_R^{1/\gamma} - E_Y'\right) \cos\omega_s t + \frac{1}{2{\cdot}03}\left(E_B^{1/\gamma} - E_Y'\right) \sin\omega_s t$$

$$\text{where } E_Y' = 0{\cdot}3E_R^{1/\gamma} + 0{\cdot}59E_G^{1/\gamma} + 0{\cdot}11E_B^{1/\gamma}$$

whence, from (16), (17), (18) and (19)

$$Y = 0{\cdot}3E_R + 0{\cdot}59E_G + 0{\cdot}11E_B$$

$$\left.\begin{aligned} a &= \gamma\left(0{\cdot}3 \, E_R^{(\gamma-1)/\gamma} + 0{\cdot}11 \, E_B^{(\gamma-1)/\gamma} + 0{\cdot}59 \, E_G^{(\gamma-1)/\gamma}\right) \\ b &= \gamma \, . \, 0{\cdot}342\left(E_R^{(\gamma-1)/\gamma} - E_G^{(\gamma-1)/\gamma}\right) \\ \text{and} \quad c &= \gamma \, . \, 0{\cdot}223\left(E_B^{(\gamma-1)/\gamma} - E_G^{(\gamma-1)/\gamma}\right) \end{aligned}\right\} \qquad (20)$$

For the constant-luminance system[1] with NTSC decoding, we have

$$E_M = E_Y^{1/\gamma} + \frac{1}{1{\cdot}14}\left(E_R^{1/\gamma} - E_Y^{1/\gamma}\right) \cos\omega_s t + \frac{1}{2{\cdot}03}\left(E_B^{1/\gamma} - E_Y^{1/\gamma}\right) \sin\omega_s t$$

$$\text{where } E_Y^{1/\gamma} = \left(0{\cdot}3E_R + 0{\cdot}59E_G + 0{\cdot}11E_B\right)^{1/\gamma}$$

Again from (16), (17), (18) and (19) we have

$$Y = 0{\cdot}3E_R + 0{\cdot}11E_B + 0{\cdot}59\left(1{\cdot}7E_Y^{1/\gamma} - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma}$$

$$\left.\begin{aligned} a &= \gamma\left\{0{\cdot}3 \, E_R^{(\gamma-1)/\gamma} + 0{\cdot}11 \, E_B^{(\gamma-1)/\gamma} + 0{\cdot}59\left(1{\cdot}7E_Y^{1/\gamma} - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma-1}\right\} \\ b &= \gamma \, . \, 0{\cdot}342\left\{E_R^{(\gamma-1)/\gamma} - \left(1{\cdot}7E_Y^{1/\gamma} - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma-1}\right\} \\ c &= \gamma \, . \, 0{\cdot}223\left\{E_B^{(\gamma-1)/\gamma} - \left(1{\cdot}7E_Y^{1/\gamma} - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}\right)^{\gamma-1}\right\} \end{aligned}\right\} \qquad (21)$$

4. NON-LINEAR DECODING

If certain non-linear processes are incorporated, the decoder of Fig. 2 may be used to derive $E_G^{1/\gamma}$ correctly from a composite signal of the constant-luminance type. Fig. 3 shows details of the non-linear decoder.

For the constant-luminance signal

$$E_M = E_Y^{1/\gamma} + \frac{1}{K_1}\left(E_R^{1/\gamma} - E_Y^{1/\gamma}\right)\cos\omega_s t + \frac{1}{K_2}\left(E_B^{1/\gamma} - E_Y^{1/\gamma}\right)\sin\omega_s t \qquad (22)$$

In the presence of noise, we again use the general equations (7) and (8), re-written below as (23) and (24):

$$S_R = E_R^{1/\gamma} + N_Y + K_1 N'_c \qquad (23)$$

$$S_B = E_B^{1/\gamma} + N_Y + K_2 N''_c \qquad (24)$$

Fig. 3 shows the formation of $E_G^{1/\gamma}$ which becomes the signal applied to the "green" gun,

$$S_G = \left\{1{\cdot}7\left(E_Y^{1/\gamma} + N_Y\right)^{\gamma} - 0{\cdot}51\left(E_R^{1/\gamma} + N_Y + K_1 N'_c\right)^{\gamma} - 0{\cdot}19\left(E_B^{1/\gamma} + N_Y + K_2 N''_c\right)^{\gamma}\right\}^{1/\gamma} \qquad (25)$$

from (23), (24), (25) and (11), we have

$$L_R = E_R + \gamma\, E_R^{(\gamma-1)/\gamma}\left(N_Y + K_1 N'_c\right)$$

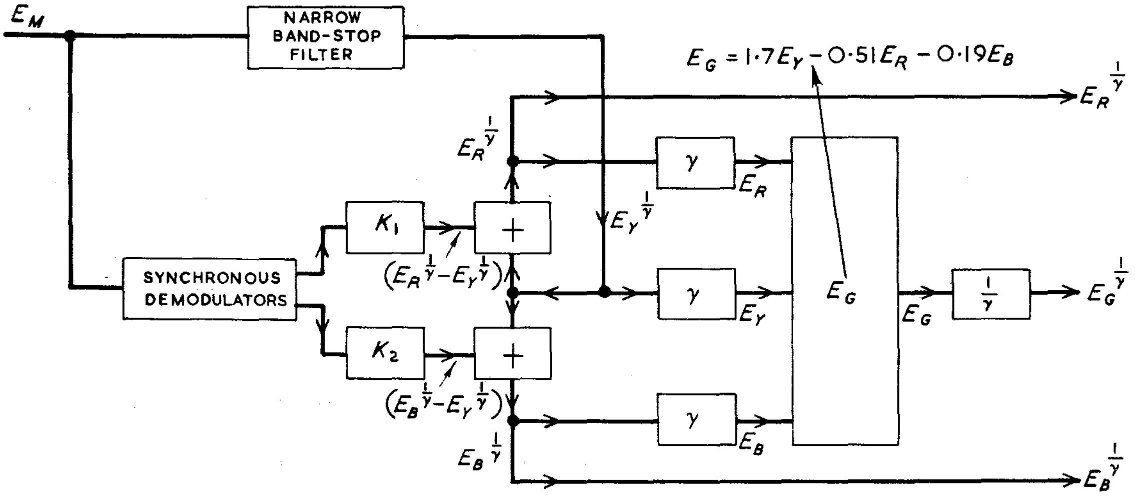

Fig. 3 - Non-linear decoder

$$L_B = E_B + \gamma\, E_B^{(\gamma-1)/\gamma}\left(N_Y + K_2 N''_c\right) \qquad (27)$$

$$\begin{aligned} L_G &= 1{\cdot}7\left(E_Y^{1/\gamma} + N_Y\right)^{\gamma} - 0{\cdot}51\left(E_R^{1/\gamma} + N_Y + K_1 N'_c\right)^{\gamma} - 0{\cdot}19\left(E_B^{1/\gamma} + N_Y + K_2 N''_c\right)^{\gamma} \\ &= E_G + \gamma\left\{ N_Y\left(1{\cdot}7\, E_Y^{(\gamma-1)/\gamma} - 0{\cdot}51\, E_R^{(\gamma-1)/\gamma}\right) - 0{\cdot}19\, E_B^{(\gamma-1)/\gamma} \right\} \\ &\qquad\qquad - 0{\cdot}51\, K_1 N'_c\, E_R^{(\gamma-1)/\gamma} - 0{\cdot}19\, K_2 N''_c\, E_B^{(\gamma-1)/\gamma} \Bigg\} \end{aligned} \qquad (28)$$

From (26), (27) and (28), the total luminance is

$$\begin{aligned} Y_T &= 0{\cdot}3E_R + 0{\cdot}59E_G + 0{\cdot}11E_B + \gamma \,.\, N_Y \,.\, E_Y^{(\gamma-1)/\gamma} \\ &= E_Y + \gamma \,.\, N_Y \,.\, E_Y^{(\gamma-1)/\gamma} \end{aligned} \qquad (29)$$

whence $Y = E_Y$

$a = \gamma \,.\, E_Y^{(\gamma-1)/\gamma}$

$b = 0$

and $c = 0$

5. RESULTS AND DISCUSSION

Expressions defining Y, a, b and c have been obtained for various combinations of composite signal and receiver decoder. By applying these expressions, the "r.m.s. visibilities" of l.f. and h.f. noise have been determined for a series of test colours[5] (after normalization for white luminance) together with the three saturated additive primaries and white. The ratio f_c/f_o was assumed equal to 1/8.

No attempt has been made to derive results representing the combined visibility of l.f. and h.f. noise. There is some evidence[6] that masking of low-frequency fluctuations by high-frequency components would make such a result rather suspect.

Table 1 shows the "visibilities" of the noise displayed when using three different signal/decoder combinations. The results are tabulated in terms of both the Fechner fraction $\Delta Y/Y$ and the relative unit, the decilum.*

*Relative visibility $= 20 \log_{10} \dfrac{\Delta Y_1/Y_1}{\Delta Y_2/Y_2}$ decilums. The reference level for the columns showing decilums is, in all cases, the Fechner fraction of the noise at white luminance.

TABLE 1

Uncorrected "visibilities" of l.f. and h.f. noise

				NTSC system with NTSC decoder				Constant-luminance system with NTSC decoder				Constant-luminance system with non-linear decoder			
colour	E_R	E_G	E_B	$\frac{\Delta Y_{LF}}{Y}$	l.f. noise vis. dl	$\frac{\Delta Y_{HF}}{Y}$	h.f. noise vis. dl	$\frac{\Delta Y_{LF}}{Y}$	l.f. noise vis. dl	$\frac{\Delta Y_{HF}}{Y}$	h.f. noise vis. dl	$\frac{\Delta Y_{LF}}{Y}$	l.f. noise vis. dl	$\frac{\Delta Y_{HF}}{Y}$	h.f. noise vis. dl
Red	0·468	0·068	0·084	1·70	6·79	3·91	5·62	1·56	6·04	3·82	5·39	1·63	6·42	4·32	6·44
Yellow	1·061	0·628	0·047	0·923	1·45	2·35	1·18	0·885	1·10	2·25	0·798	0·920	1·44	2·42	1·43
Green	0·119	0·467	0·107	1·34	4·71	3·28	4·08	1·09	2·92	3·07	3·50	1·30	4·45	3·43	4·45
Cyan	0·047	0·256	0·223	1·66	6·57	4·13	6·06	1·58	6·15	3·87	5·51	1·63	6·42	4·32	6·44
Blue	0·017	0·014	0·274	3·35	12·7	6·72	10·3	2·87	11·3	6·64	10·2	3·19	12·2	8·43	12·3
R	1·000	0	0	1·47	5·53	2·05	0	1·16	3·46	2·67	2·29	1·33	4·64	3·52	4·68
G	0	1·000	0	1·09	2·92	2·05	0	0·812	0·34	1·53	−2·53	0·984	2·01	2·60	2·06
B	0	0	1·000	2·38	9·71	2·05	0	1·61	6·32	3·29	4·11	2·10	8·61	5·55	8·66
White	1·000	1·000	1·000	0·779	0	2·05	0	0·779	0	2·05	0	0·779	0	2·05	0

TABLE 2

Corrected relative "visibilities" of h.f. and l.f. noise

	NTSC system with NTSC decoder						Constant-luminance system with NTSC decoder						Constant-luminance system with non-linear decoder					
Colour	l.f. noise vis. 50:1 contrast	Corrected l.f. noise vis. (low adapt.)	Corrected l.f. noise vis. (high adapt.)	h.f. noise vis. 50:1 contrast	Corrected h.f. noise vis. (low adapt.)	Corrected h.f. noise vis. (high adapt.)	l.f. noise vis. 50:1 contrast	Corrected l.f. noise vis. (low adapt.)	Corrected l.f. noise vis. (high adapt.)	h.f. noise vis. 50:1 contrast	Corrected h.f. noise vis. (low adapt.)	Corrected h.f. noise vis. (high adapt.)	l.f. noise vis. 50:1 contrast	Corrected l.f. noise vis. (low adapt.)	Corrected l.f. noise vis. (high adapt.)	h.f. noise vis. 50:1 contrast	Corrected h.f. noise vis. (low adapt.)	Corrected h.f. noise vis. (high adapt.)
	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl
Red	6·1	5·1	2·1	4·9	3·9	0·9	5·4	4·4	1·9	4·8	3·8	1·3	5·7	4·7	1·7	5·8	4·8	1·8
Yellow	1·4	1·4	0·9	1·1	1·1	0·6	1·0	1·0	0·5	0·7	0·7	0·2	1·4	1·4	0·9	1·4	1·4	0·9
Green	4·2	3·7	2·2	3·7	3·2	1·7	2·6	2·1	0·6	3·2	2·7	1·2	4·0	3·5	2·0	4·1	3·6	2·1
Cyan	5·9	4·9	1·9	5·3	4·3	1·3	5·5	4·5	2·0	4·9	3·9	1·4	5·7	4·7	1·7	5·8	4·8	1·8
Blue	9·5	6·5	−0·5	7·2	4·2	−2·8	8·9	6·4	0·9	7·8	5·3	−0·2	9·1	6·1	−0·9	9·2	6·2	−0·8
R	5·1	4·6	2·6	−0·4	−0·9	−2·9	3·2	2·7	1·7	2·1	1·6	0·6	4·2	3·7	1·7	4·3	3·8	1·8
G	2·7	2·7	1·7	−0·1	−0·1	−1·1	0·4	0·4	0·4	−2·6	−2·6	−2·6	1·8	1·8	0·8	1·9	1·9	0·9
B	8·4	6·4	2·4	−1·3	−3·3	−7·3	5·7	4·7	2·2	3·5	2·5	0	7·4	5·4	1·4	7·4	5·4	1·4
White	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

An attempt has also been made, in Table 2, to present results corrected for two additional factors. These are:

(a) variation in the Fechner fraction $\Delta Y/Y$ as a function of luminance level Y and

(b) the available maximum contrast of the viewed picture.

The corrections[7] have been deduced assuming

(i) that the relative visibility of noise over a certain scale of luminance (with different colours) is the same as that over an equivalent grey scale.

(ii) that the white display luminance is 10 foot-lamberts and the contrast ratio is limited, by ambient and flare light, to 50:1.

Tables 1 and 2 show that, for the saturated colours likely to be encountered in practice, the constant-luminance system is characterized by only a slightly reduced sensitivity to fluctuation noise when compared with the normal form of NTSC system. This is well illustrated in Table 2 where, for example, the l.f. noise visibility for any one of the five test colours (red, yellow, green, cyan and blue), viewed in low-level ambient illumination, does not vary by more than 1·6 dl° for the three signal/decoder combinations. In these same conditions, the corresponding maximum variation of h.f. noise visibility is 2 dl.

Although the results given here have been obtained using a somewhat simplified theoretical approach, it would appear that there is a reasonable degree of agreement with practical experience. This may be illustrated by the following argument. A perfect constant-luminance colour television system may be regarded as a conventional monochrome system to which a signal describing chromaticity only has been added; the "noise sensitivity" of such a system would be essentially identical to that of the monochrome system alone. It has been shown, both in the U.S.A.[8] and in Britain,[9] that the normal form of NTSC system is only some 1 or 2 dB more sensitive to fluctuation noise than the equivalent monochrome system.

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APPENDIX

If a signal $E \cos\omega_s t$ is applied to a synchronous detector, the local carrier phase may be chosen to coincide with that of the signal to be demodulated so that the output of the detector is represented by

$$E \cos\omega_s t \; . \; \cos\omega_s t = E/2 \; (1 + \cos 2\omega_s t)$$

whence after filtering

$$E_s = E/2 \tag{30}$$

Referring to Fig. 1, the wide-band instantaneous noise N_Y is first filtered to a band extending from $f_s - f_c$ to $f_s + f_c$.

The filtered noise may be written[10]

$$N = x(t) \cos\omega_s t + y(t) \sin\omega_s t \tag{31}$$

where $x(t)$ and $y(t)$ are "slowly varying" functions of time.

The r.m.s. value of the filtered noise, in terms of the wide-band noise is

$$\left(\overline{N^2}\right)^{\frac{1}{2}} = \left(\overline{N_Y^2}\right)^{\frac{1}{2}} \; . \; \left(2f_c/f_o\right)^{\frac{1}{2}} \tag{32}$$

The r.m.s. values of the in-phase and quadrature components are evidently equal to each other because the components share the total power equally:

$$\begin{aligned} \left[\overline{\{x(t) \cos\omega_s t\}^2}\right]^{\frac{1}{2}} &= \left[\overline{\{y(t) \sin\omega_s t\}^2}\right]^{\frac{1}{2}} \\ &= \left(\overline{N_Y^2}\right)^{\frac{1}{2}} \; . \; (f_c/f_o)^{\frac{1}{2}} \end{aligned} \tag{33}$$

Now

$$\begin{aligned} \left[\overline{\{x(t) \cos\omega_s t\}^2}\right]^{\frac{1}{2}} &= \left[\frac{1}{T}\int_0^T \{x(t) \cos\omega_s t\}^2 \; . \; dt\right]^{\frac{1}{2}} \\ &= \left[\frac{1}{2T}\int_0^T \{x(t)\}^2 \; . \; dt + \frac{1}{2T}\int_0^T \{x(t)\}^2 \cos 2\omega_s t . dt\right]^{\frac{1}{2}} \end{aligned}$$

If T is large, we have

$$\begin{aligned} \left[\overline{\{x(t) \cos\omega_s t\}^2}\right]^{\frac{1}{2}} &= \left[\frac{1}{2T}\int_0^T \{x(t)\}^2 \; . \; dt\right]^{\frac{1}{2}} \\ &= \frac{1}{\sqrt{2}}\left[\overline{\{x(t)\}^2}\right]^{\frac{1}{2}} \end{aligned} \tag{34}$$

After synchronous detection, the in-phase noise is

$$N' = x(t) \cos\omega_s t \,.\, \cos\omega_s t$$

$$= x(t)/2 \tag{35}$$

if we assume that the component at the frequency $2\omega_s/2\pi$ has been removed by a suitable filter.

Whence r.m.s. noise

$$\left(\overline{N'^2}\right)^{\frac{1}{2}} = \frac{1}{2}\left[\overline{\{x(t)\}^2}\right]^{\frac{1}{2}}$$

$$= \frac{\sqrt{2}}{2} \,.\, \left[\overline{\{x(t)\ \cos\omega_s t\}^2}\right]^{\frac{1}{2}} \quad \text{(from (34))}$$

whence from (33) $= \dfrac{\sqrt{2}}{2} \,.\, \left(\overline{N_Y^2}\right)^{\frac{1}{2}} \,.\, \left(f_c/f_o\right)^{\frac{1}{2}}$ (36)

Normalizing both signal and noise amplitudes for unity gain we have, from (30) to (36),

Signal component $E_s = E$ (37)

and the r.m.s. noise $\left(\overline{N'^2}\right)^{\frac{1}{2}} = \left(\overline{N_Y^2}\right)^{\frac{1}{2}} \,.\, \left(2f_c/f_o\right)^{\frac{1}{2}}$ (38)

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